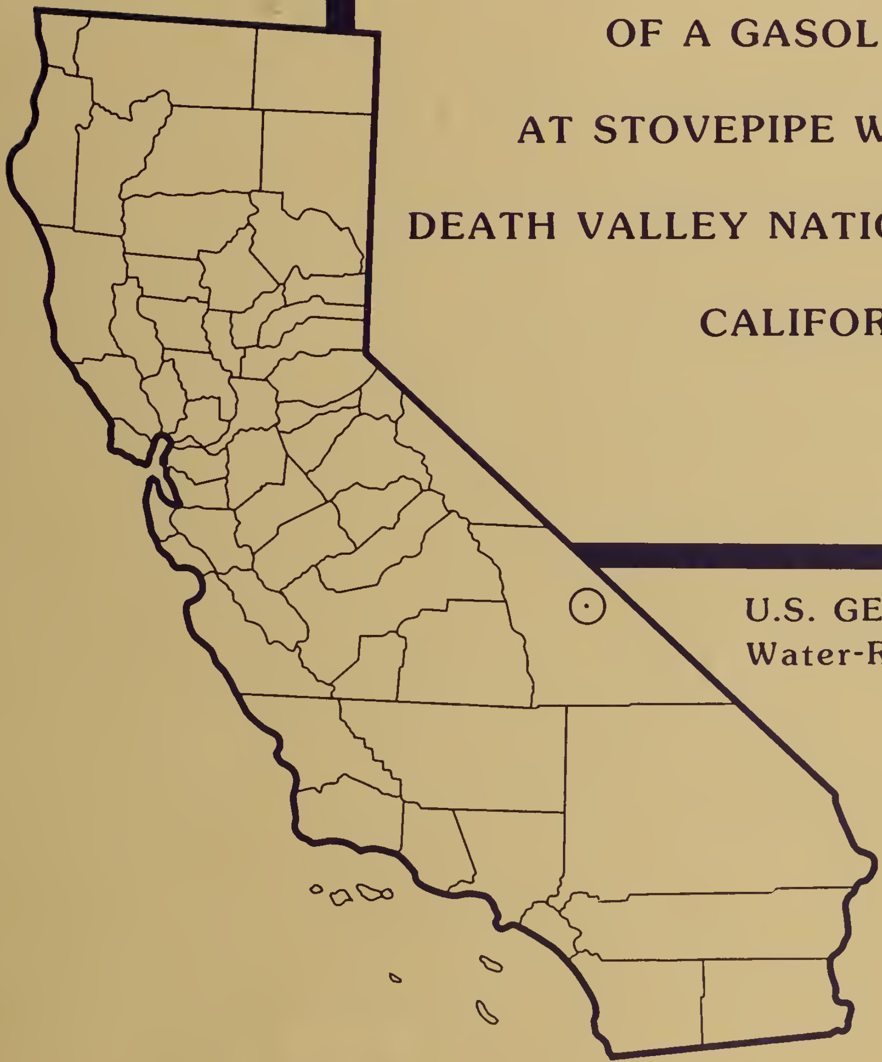
DELINEATION AND HYDROLOGIC EFFECTS OF A GASOLINE LEAK AT STOVEPIPE WELLS HOTEL DEATH VALLEY NATIONAL MONUMENT CALIFORNIA



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Ground water is the only local source of water available to the Stovepipe Wells Hotel facilities of the Death Valley National Monument, California. A leak in a service station storage tank caused the formation of a gasoline layer overlying the water table, creating the potential for contamination of the water supply. The maximum horizontal extent of the gasoline layer was mathematically estimated to be 1,300 feet downgradient from the leaky gasoline tank. Exploratory drilling detected the gasoline layer between 900 and 1,400 feet downgradient and between 50 and 150 feet upgradient from the source. Traces of the soluble components of gasoline were also found in the aquifer 150 feet upgradient, and 250 feet distant from the source perpendicular to the direction of ground-water movement. The gasoline leak is not likely to have an effect on the supply wells located 0.4 mile south of the leak source, which is nearly perpendicular to the direction of ground-water movement and the primary direction of gasoline movement in the area. No effect on phreatophytes 2 miles downgradient from the layer is likely, but the potential effects of gasoline vapors within the unsaturated zone on local xerophytes are not known.

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By ANTHONY BUONO and ELAINE M. PACKARD

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July 1982

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
2800 Cottage Way, Room W-2235
Sacramento, Calif. 95825

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CONVERSION FACTORS

For those readers who may prefer metric (SI) units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
acres	0.4047	ha (hectares)
ft (feet)	0.3048	m (meters)
ft^2/d (feet squared per day)	0.0929	m^2/d (meters squared per day)
ft^3 (cubic feet)	0.0283	m^3 (cubic meters)
gal (gallons)	3.785	L (liters)
gal/d (gallons per day)	3.785	L/d (liters per day)
gal/min (gallons per minute)	0.06309	L/s (liters per second)
(gal/min)/ft (gallons per minute per foot)	0.2070	(L/s)/m (liters per second per meter)
inches	25.4	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

Degrees Fahrenheit are converted to degrees Celsius by using the formula:
Temp °C = (temp °F - 32)/1.8

Additional abbreviations used:
- lsd - land surface datum
- mg/L - milligrams per liter
- μg/L - micrograms per liter

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

DELINEATION AND HYDROLOGIC EFFECTS OF A GASOLINE LEAK AT STOVEPIPE WELLS HOTEL, DEATH VALLEY NATIONAL MONUMENT, CALIFORNIA

By Anthony Buono and Elaine M. Packard

ABSTRACT

Ground water is the only local source of water available to the Stovepipe Wells Hotel facilities of the Death Valley National Monument, California. A leak in a service station storage tank, probably totaling more than 19,000 gallons, caused the formation of a gasoline layer overlying the water table, creating the potential for contamination of the water supply.

For the purpose of site selection for exploratory drilling, the horizontal extent of the gasoline layer was mathematically estimated to be 1,300 feet downgradient from the leaky gasoline tank. Exploratory drilling detected the gasoline layer extending between 900 and 1,400 feet downgradient and 50 and 150 feet upgradient from the source. Traces of the soluble components of gasoline were also found in the aquifer 150 feet upgradient and 250 feet distant from the source perpendicular to the direction of ground-water movement.

The gasoline leak is not likely to have an effect on the supply wells located 0.4 mile south of the leak source, which is nearly perpendicular to the direction of ground-water movement and the primary direction of gasoline movement in the area. No effect on phreatophytes 2 miles downgradient from the layer is likely, but the potential effects of gasoline vapors within the unsaturated zone on local xerophytes are not known.

INTRODUCTION

Stovepipe Wells Hotel is a National Park Service facility on State Highway 190 in the western part of Death Valley about 200 miles northeast of Los Angeles in southern California (fig. 1). In May 1979 the odor of gasoline was detected in unused well 15S/44E-36K1 (fig. 2) near the Stovepipe Wells Hotel gasoline station. Analysis of a sample collected from the well indicated that a layer of gasoline had accumulated above the water table. The gasoline had leaked from one of the station's two 8,000-gallon storage tanks located about 75 feet south of the well (fig. 2).

The National Park Service requested the U.S. Geological Survey to assess the spreading and the hydrologic effects of the gasoline leak on the ground water and vegetation of the area. Of primary concern were the hotel's supply wells 15S/44E-36Q2 and 16S/44E-1C1 about 0.4 mile south (fig. 2) of the contamination source. A map of the water-table configuration in August 1977 (Lamb and Downing, 1979, p. 7) indicated that a local pumping depression might surround the supply wells. The depression could cause the movement of gasoline toward those wells and jeopardize the area's only water supply.

Geography and Climate

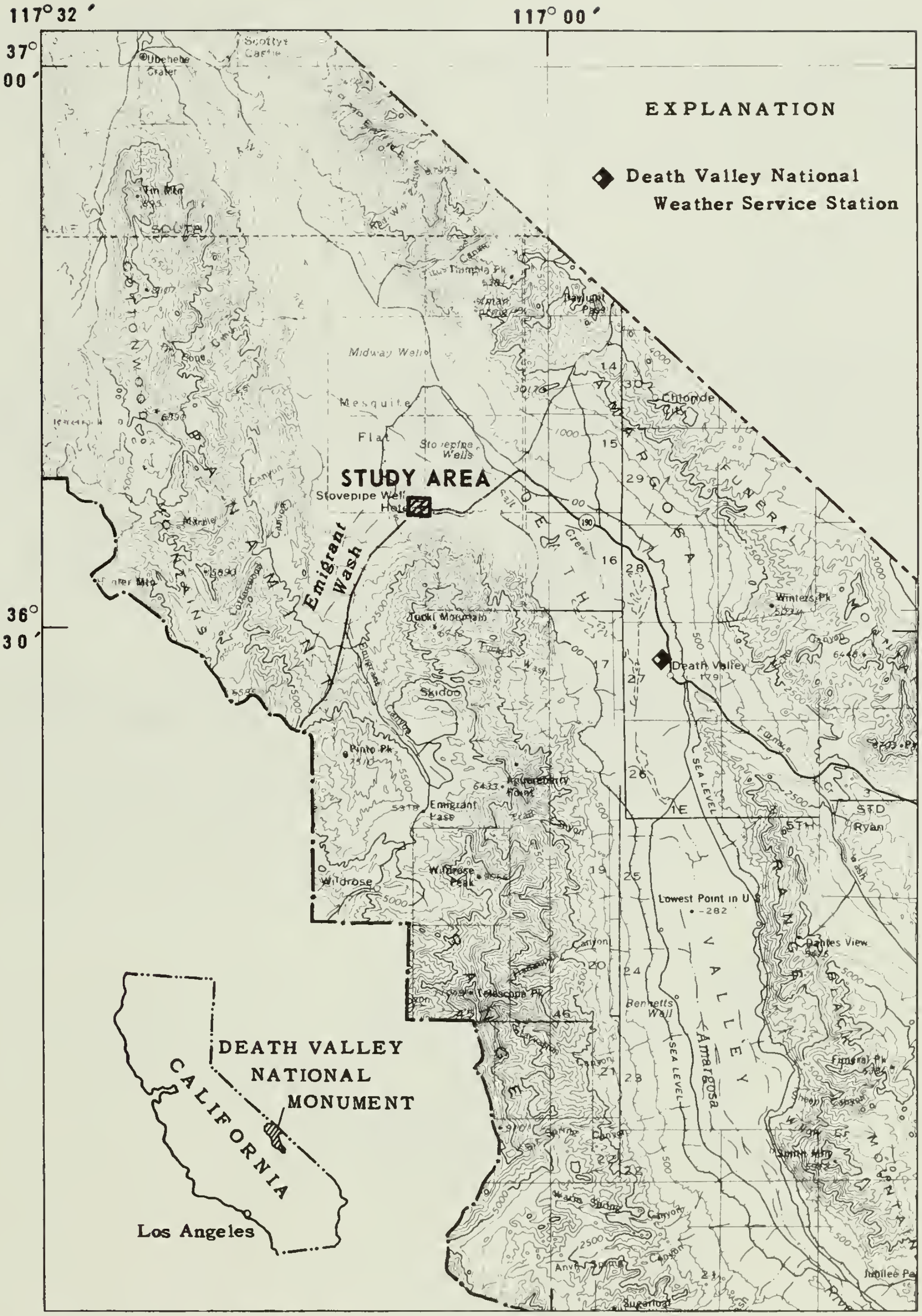
Death Valley is a 140-mile-long northwestward-trending desert basin in the southwestern part of the Great Basin. The valley, bounded on the east by the Amargosa Range and on the west by the Panamint Range, is famous as the site of the lowest point in the United States at 282 feet below sea level (fig. 1).

The climate in Death Valley is arid, with an average annual rainfall of less than 2 inches and an average monthly temperature ranging from 52°F in January to 102°F in July. Measurements have been recorded since 1913 at the National Weather Service Station at Death Valley, Calif., altitude 194 feet below sea level, about 18 miles southeast of the study area (fig. 1). The highest temperature recorded at this station was 134°F on July 10, 1913.

Purpose and Scope

The purposes of the investigation were to delineate the horizontal extent of the gasoline layer overlying the water table, to assess the effects of the gasoline layer on the ground water and vegetation of the area, with emphasis on the potential effects on water supply, and to determine what measures may be needed to insure continued safe use of local ground water.

The area of investigation was less than 1 mi^2 surrounding the Stovepipe Wells Hotel. The study involved the evaluation of ground-water levels and water-quality information, and exploratory drilling for the collection and analysis of soil samples for gasoline content above and below the water table in the vicinity of the gasoline leak.

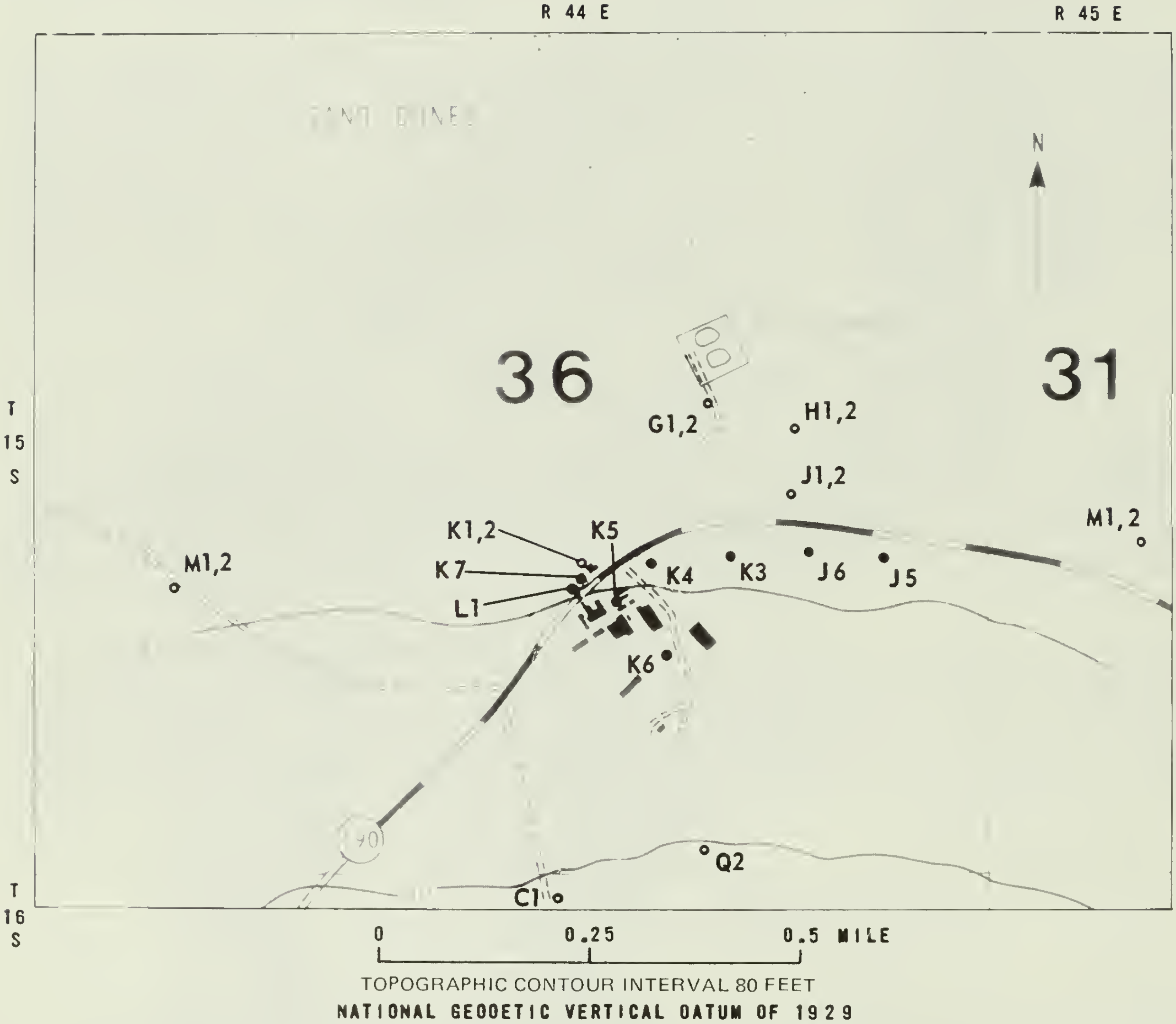


Base from U.S. Geological Survey,
California (South half) 1:500,000, 1970

0 10 20 30 MILES

CONTOUR INTERVAL 500 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

FIGURE 1.--Location of study area in Death Valley National Monument, California.



EXPLANATION

WELL--

o M1,2 Drilled prior to May 1980

• J5 Drilled May 1980

FIGURE 2.--Location of wells.

Approach

The objectives of the investigation were accomplished by the evaluation of ground-water levels, water-quality information, well-construction information, well logs, and gasoline station operation records; determination of the direction of ground-water movement; test-hole drilling with split-spoon soil sampling above and below the water table; and the conversion of test holes to monitor wells for the collection of periodic water-level and water-quality data for the detection of continued gasoline movement.

Previous Investigations

Information from previous studies in Death Valley used during this investigation included: General background information concerning the climatic, hydrologic, and geologic setting from Hunt, Robinson, Bowles, and Washburn (1966); ground-water quality data from Miller (1977); and ground-water level and quality data from Lamb and Downing (1979).

Well-Numbering System

Wells are numbered according to their location in the rectangular system for the subdivision of public lands. For example, in the number 15S/44E-36K1, the part of the number preceding the slash indicates the township (T. 15 S.), the part between the slash and the hyphen indicates the range (R. 44 E.), the number between the hyphen and the letter indicates the section (sec. 36), and the letter indicates the 40-acre subdivision of the section, as shown in the diagram below. Within the 40-acre tract, wells are numbered serially as indicated by the final digit.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Acknowledgments

The authors express their appreciation for the cooperation of the National Park Service personnel during the investigation, in particular, Gerard S. Witucki of the Western Regional office; and George Von der Lippe, Bob Quesenberry, and Richard S. Rayner of Death Valley National Monument.

The local water supply is obtained from two wells, 15S/44E-36Q2 and 16S/44E-1C1 (fig. 2), that penetrate the unconfined aquifer composed of unconsolidated gravelly sandy silt. Aquifer transmissivity was estimated to be 3,400 ft^2/d based on the Jacob and Lohman straight line solution for well recovery data (Lohman, 1972, p. 26-27) from a specific capacity test run by the Park Service on well 1C1 in 1973. The specific capacity of the well is about 7 (gal/min)/ft of drawdown in the well.

Each supply well produces about 25,000 gal/d during peak seasonal use at a pumping rate of 65 gal/min in well 15S/44E-36Q2 and 23 gal/min in well 16S/44E-1C1. Well 36Q2 supplies most of the area's nonpotable uses, and well 1C1 supplies all potable and some nonpotable uses after reverse-osmosis treatment at the well site. The wells penetrate deeper in the aquifer than other local wells and produce the best quality water in the area, although the dissolved-solids concentration of about 3,000 mg/L (table 1) is six times the recommended limit for drinking water (U.S. Environmental Protection Agency, 1976, p. 205-206). Table 1 shows water-level, well-construction, and dissolved-solids information for all local wells.

According to a 1977 water-table map (Lamb and Downing, 1979, p. 7) the direction of ground-water movement in the study area was southward toward the local supply wells. This direction of ground-water movement was the cause of great concern over the possible impact of the gasoline leak on the supply wells 0.4 mile to the south. During the present investigation, altitudes of well-measuring points were more accurately determined by use of a surveyor's leveling instrument. Using this information, new water-table maps were drawn, and a better understanding of the direction of local ground-water movement was obtained.

Figure 3 shows a comparison of the water-table configurations for April 1977 and June 1980. The map indicates that ground-water movement is eastward, nearly perpendicular to the alinement of the leak site and the supply wells. The figure also shows a general decline in water levels of about 0.25 foot, indicated by the westward shift of contours, and no change in the direction and pattern of ground-water movement. Hydrographs of several wells (fig. 4) show a declining trend over the period of record along with seasonal fluctuations in water levels. Included is a hydrograph of well 15S/44E-34D1 (off fig. 2 to west), 2.5 miles northwest of the supply wells, which also shows a declining trend in water levels. The hydrographs indicate that part of the decline observed in figure 3 resulted from seasonal fluctuations, because measurements were made in different months in 1977 and 1980, and part from regional decline. Together these data indicate that the present rate of withdrawal from the supply wells has had no noticeable effect on water levels or patterns of ground-water movement in the area.

TABLE 1. - Water-level data, well data, and dissolved-solids concentrations in the Stovepipe Wells Hotel area

[Analyses by the U.S. Geological Survey Central Laboratory, Arvada, Colo., unless otherwise noted]

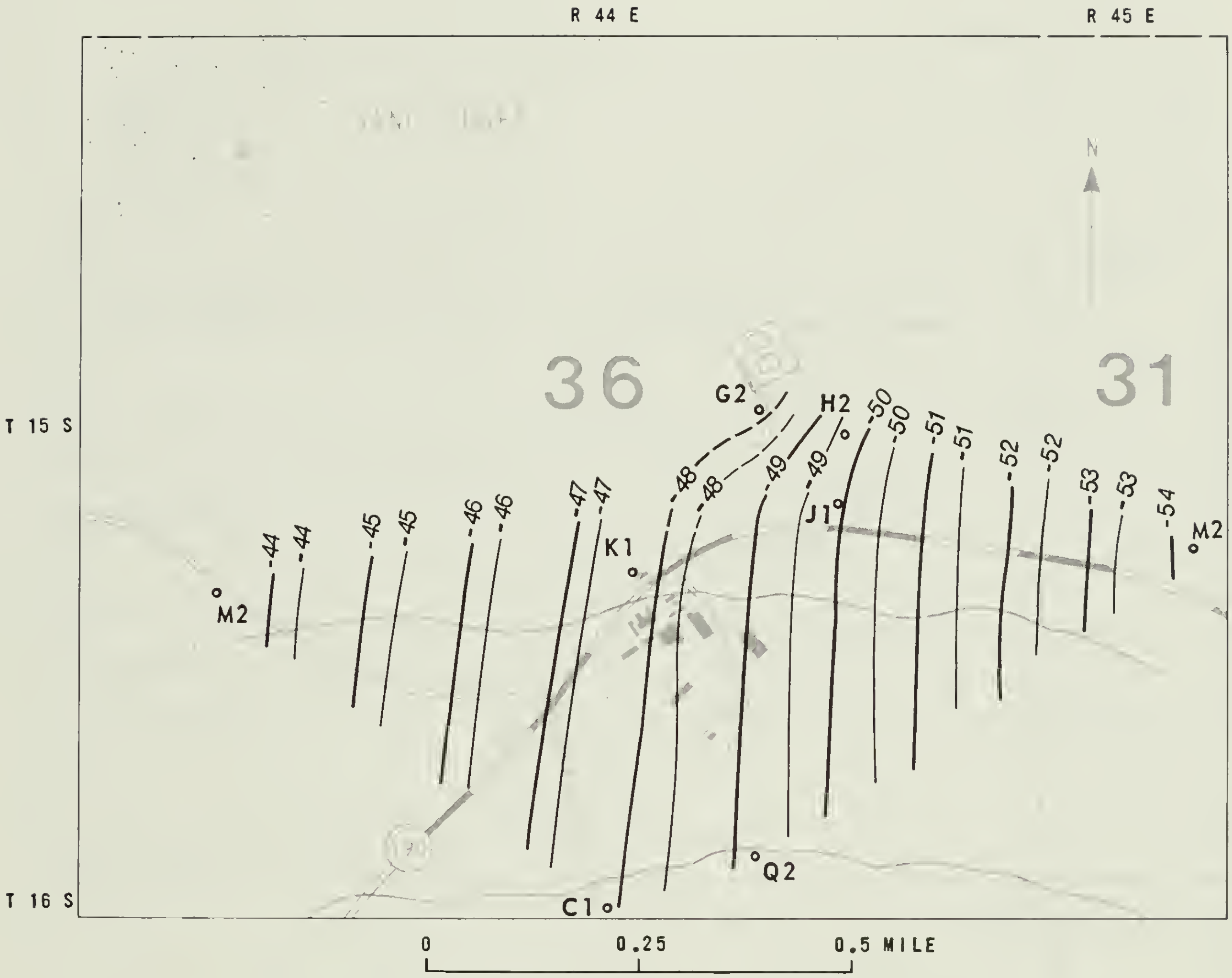
Site / Date	Altitude of lsd (feet above or below (-) sea level)	Depth to water (feet below lsd)	Perforated interval (feet below lsd)	Depth of well (feet below lsd)	Dissolved solids, calculated sum (mg/L)
15S/44E-34D1					
3-26-68[1]	15.41	38.17	51.0-53.0	53	3,290
15S/44E-36G1					
6-17-80	-25.21	22.78	44.9-46.9	46.9	--
15S/44E-36G2					
6-17-80	-25.31	22.46	24.7-27.7	27.7	8,080
15S/44E-36H1					
11-03-73	-26.20	22.25	49.2-51.2	51.2	5,430
6-17-80	--	23.53	--	--	5,580
15S/44E-36H2					
6-17-80	-26.10	23.80	25.2-28.2	28.2	--
15S/44E-36J1					
6-17-80	-22.76	27.22	48.2-50.2	50.2	6,410
15S/44E-36J5					
6-17-80	-15.30	36.26	32.6-44.3	44.3	8,260
15S/44E-36J6					
6-17-80	-12.64	37.42	36.0-46.0	46.0	5,390
15S/44E-36K1					
3-21-67	-9.84	--	37(?)-65(?)	65	9,170
2-14-74	--	37.57	--	--	--
2-27-75	--	37.67	--	--	--
6-23-76	--	37.66	--	--	--
4-05-77	--	37.61	--	--	--
5-10-78	--	37.57	--	--	11,200
5-09-79[1]	--	37.55	--	--	10,000
6-18-80	--	37.86	--	--	8,790
15S/44E-36K2					
2-14-74	-9.98	37.37	Unknown	50	--
2-27-75	--	37.53	--	--	--
6-23-76	--	37.49	--	--	--
4-06-77[1]	--	37.51	--	--	3,270
5-10-78	--	37.53	--	--	3,570
5-09-79	--	37.60	--	--	3,770
15S/44E-36K3					
6-17-80	-9.66	39.42	37.4-45.4	45.4	5,250
15S/44E-36K4					
6-17-80	-7.98	40.53	38.0-47.0	47.0	5,570
15S/44E-36K5					
6-18-80	.73	49.06	49.8-59.8	59.8	6,400

See footnotes at end of table.

TABLE 1. - Water-level data, well data, and dissolved-solids concentrations in the Stovepipe Wells Hotel area--Continued

Site / Date	Altitude of lsd (feet above or below (-) sea level)	Depth to water (feet below lsd)	Perforated interval (feet below lsd)	Depth of well (feet below lsd)	Dissolved solids, calculated sum (mg/L)
15S/44E-36K6					
6-18-80	14.46	63.62	62.0-71.7	71.7	6,790
15S/44E-36K7					
6-17-80	-5.23	42.53	37.0-54.0	54.0	7,650
15S/44E-36L1					
6-17-80	-1.85	45.07	44.3-54.4	54.4	6,370
15S/44E-36M1					
11-03-73	-15.22	28.1	43.7-45.7	45.7	6,610
2-26-76	--	--	--	--	6,490
4-06-77[1]	--	27.88	--	--	6,620
5-10-78	--	27.84	--	--	6,570
9-21-78	--	28.04	--	--	6,230
5-09-79[1]	--	28.01	--	--	6,580
6-18-80	--	28.20	--	--	6,220
15S/44E-36M2					
11-03-73	-15.33	18.46	30.4-33.4	33.4	7,260
15S/44E-36Q2					
5-08-67[1]	81.05	--	Unknown	>300	2,980
9-09-73[2]	--	130.25	--	--	--
6-19-75	--	--	--	--	2,780
2-26-76	--	--	--	--	2,840
4-06-77[1]	--	129.98	--	--	2,910
5-10-78	--	130.02	--	--	2,720
5-10-79[1]	--	130.23	--	--	2,920
6-18-80	--	130.25	--	--	2,730
15S/45E-31M1[3]					
2-26-76	-26.50	27.57	35.7-37.7	37.7	2,990
4-06-77[1]	--	27.25	--	--	5,540
5-10-78	--	27.29	--	--	9,260
9-21-78	--	27.45	--	--	8,340
5-10-79[1]	--	27.42	--	--	8,830
6-18-80	--	27.67	--	--	8,180
15S/45E-31M2[4]					
6-17-80	-26.64	27.59	28.3-30.3	30.3	--
16S/44E-1C1					
9-09-73	97.19	145.4	264-294	294	--
4-06-77[1]	--	144.84	--	--	2,870
5-10-78	--	144.67	--	--	2,960
5-10-79[1]	--	144.90	--	--	2,890

[1]Analysis by California Department of Water Resources.
[2]Analysis by National Park Service.
[3]Formerly 15S/44E-36J3.
[4]Formerly 15S/44E-36J4.



TOPOGRAPHIC CONTOUR INTERVAL 80 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

WATER-TABLE CONTOUR--Shows altitude of water table. Dashed where approximately located. Contour interval 1 foot. National Geodetic Vertical Datum of 1929

M2 WELL AND NUMBER

-53 April 1977

-54 June 1980

FIGURE 3.--Water-table configurations, April 1977 and June 1980.

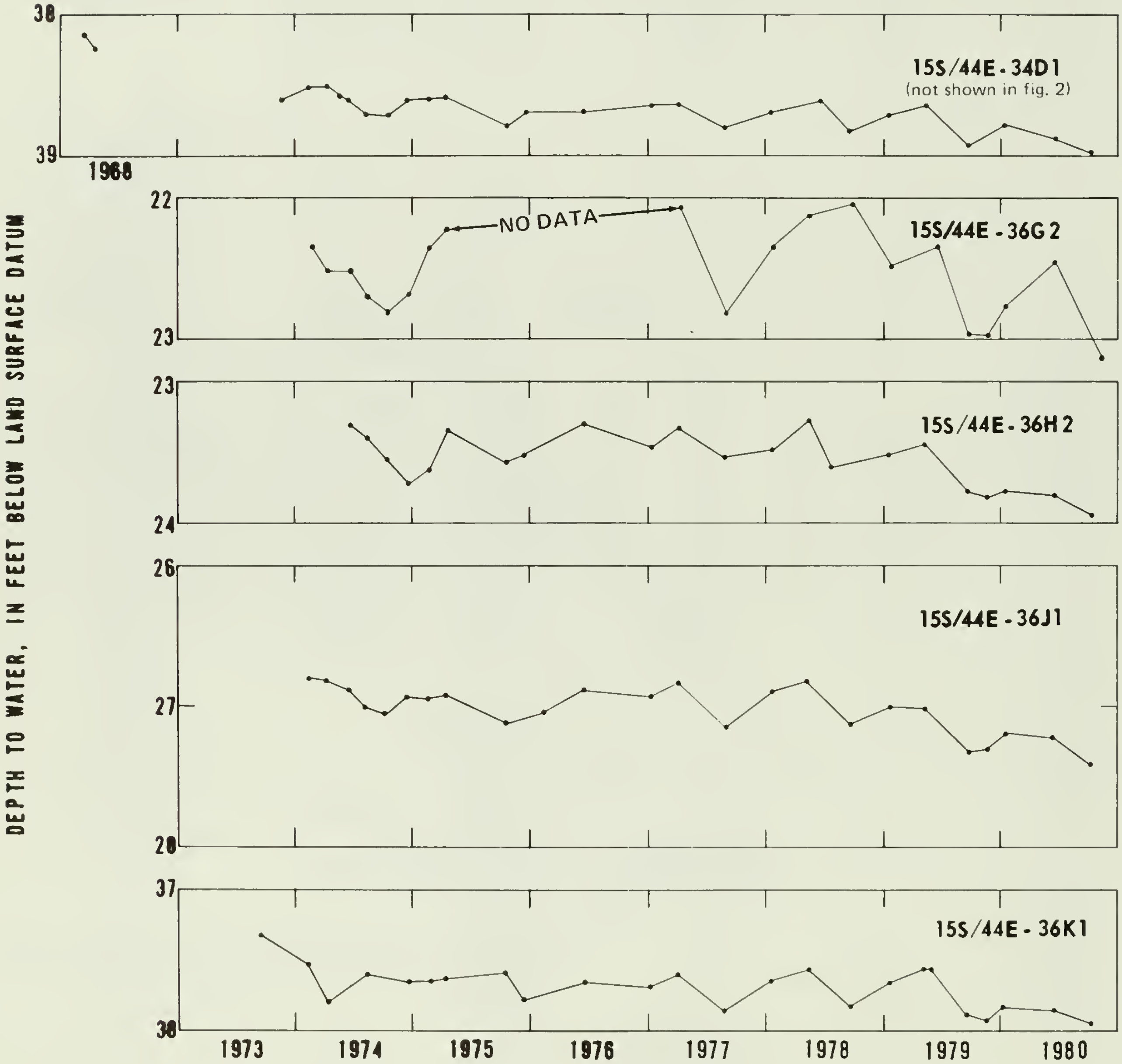


FIGURE 4.--Hydrographs of selected wells in the Stovepipe Wells Hotel area, 1968, 1973--80.

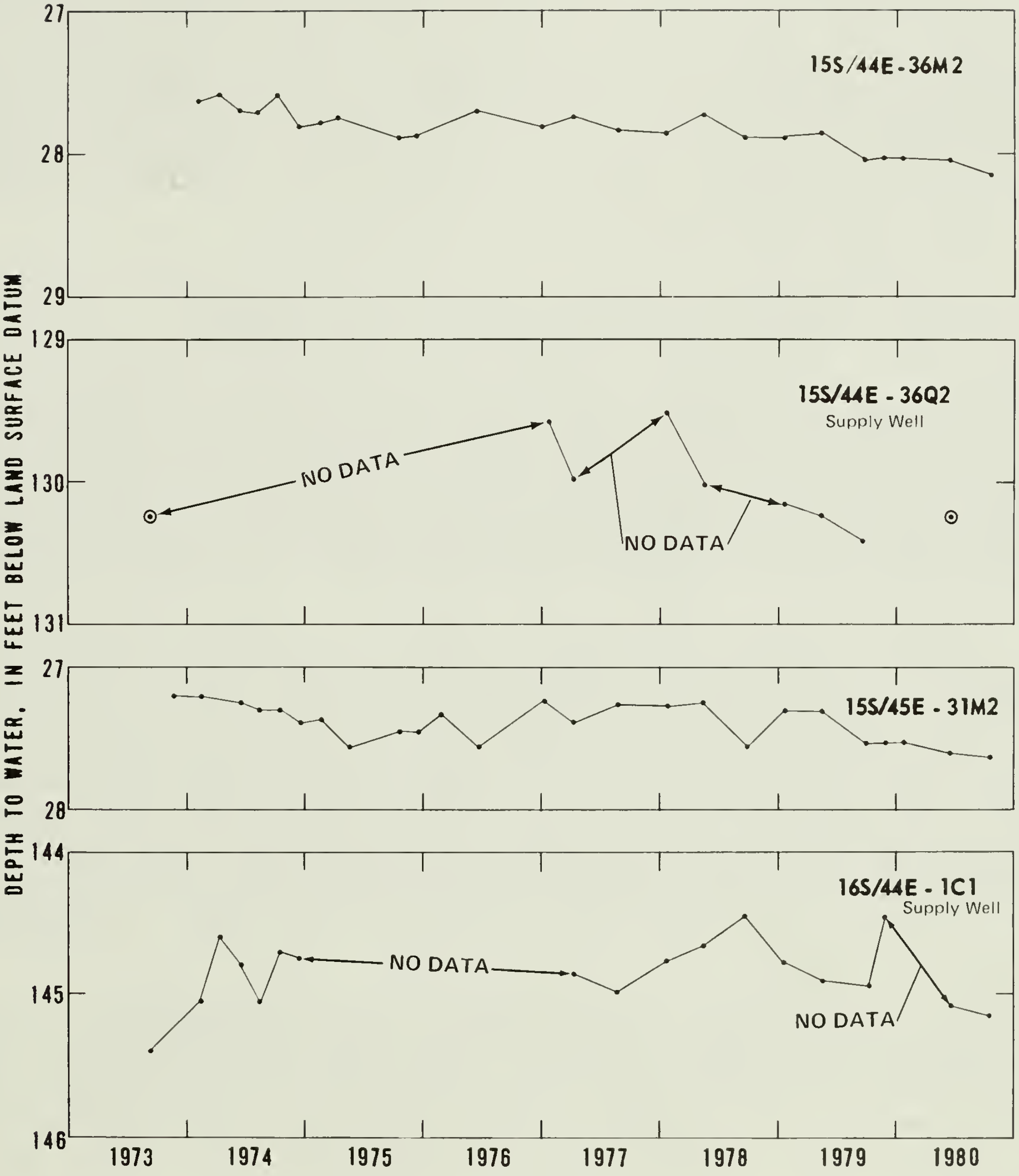


FIGURE 4.--Continued.

After the detection of a gasoline odor in well 15S/44E-36K1 (fig. 2) in May 1979, a gas chromatograph mass spectrometry analysis for hydrocarbon concentration was run on a sample taken at the liquid surface in the well. The sample was determined to be undiluted gasoline, indicating that a layer of gasoline had formed overlying the water table in the area. The well is directly behind the hotel's grocery store/gasoline station. Pressure testing of the station's two gasoline storage tanks in August 1979 indicated a leak in the upper part of the tank containing unleaded gasoline, 30-35 feet above the water table. Use of the tank was discontinued immediately.

Movement of a Gasoline Leak in a Porous Medium

The movement of gasoline in a porous medium, as with any liquid in the unsaturated zone, is controlled by a combination of the force of gravity and the capillary characteristics of the medium and liquid. These factors cause vertical (gravitational plus capillary forces) and lateral (capillary forces) movement of the gasoline away from the leak site. In the zone of gasoline leakage, gravitational forces are predominant, resulting in primarily vertical movement of the gasoline toward the water table.

Continued movement of the gasoline depends on the maintenance of a level of saturation exceeding the residual saturation of the medium. Residual saturation of an oil product is analogous to the specific retention of a medium for water. Specific retention is defined as "the ratio of (1) the volume of water which the porous rock or soil, after being saturated, will retain against the pull of gravity, to (2) the volume of rock or soil" (Lohman, 1972, p. 12). This retention can most easily be illustrated by water held suspended in a sponge by capillary forces against the pull of gravity. The volume of liquid retained by a medium is an inverse function of the grain and pore size of the medium. According to Schwille (1967, p. 35) the residual saturation for oil products will rarely exceed 5 percent of the volume of the medium. This value corresponds closely to values proposed by Dietz (1971, p. 132-133).

Dietz' discussion uses the porosity of the medium multiplied by the immobile oil saturation, a percentage of the porosity, which yields the oil saturation as a percentage of the total volume of the material affected by the leak. Immobile oil saturations ranged from 10 percent for light oil (gasoline) to 20 percent for heavy oil (lube oil, heavy fuel oil). For an assumed porosity of 35 percent for unconsolidated sands, 10-20 percent immobile oil saturation yields between 3.5 and 7 percent saturation of the total volume of the medium.

When a leak is sufficiently large to sustain the movement of gasoline to the water table, a layer will form overlying the water table. Gasoline, generally considered insoluble and immiscible in water even though certain components of gasoline are slightly soluble in water, has a specific gravity of 0.7 times that of water. This combination of physiochemical properties causes gasoline to float as a layer above the water surface in an unconfined aquifer. The layer will move primarily downgradient, controlled by the force of gravity and the capillary forces of the medium. Horizontal and vertical movement will continue through the unsaturated zone until the degree of gasoline saturation in the layer decreases to the residual saturation of the medium.

In addition to the movement of gasoline within the layer above the water table, the volatile nature of gasoline will cause the diffusion of gasoline vapors in the unsaturated zone, and the slight solubility of certain gasoline components in water can cause the degradation of the aquifer. The slightly soluble components are primarily the aromatic constituents of the gasoline, such as benzene and toluene (Frank Allen, U.S. Environmental Protection Agency, Athens, Ga., oral commun., Dec. 1980). The exploratory objective of this investigation was limited to delineating the horizontal extent of the gasoline layer overlying the water table in the hotel area. Future monitoring of local wells will determine the extent of continued movement of the gasoline layer in addition to the concentration of the slightly soluble gasoline components in the aquifer. Diffusion of the soluble components in aquifer water results in a continuous dilution to lower concentrations as distance increases from the gasoline layer.

Two local conditions that will reduce the horizontal extent of the gasoline layer overlying the water table through increased residual gasoline saturation are the poorly sorted silty composition of the medium and the low soil-moisture content because of the arid climate. The silty medium causes a relatively high residual saturation through the associated higher capillarity. Both the fine-grained fraction of the medium and low soil moisture increase the grain surface area available for adsorption (molecular attraction forces) of the gasoline. These factors reduce the volume of gasoline available to reach the water table and increase the thickness of the layer overlying the water table.

Of additional benefit to the local ground-water system is the expected complete biodegradation and evaporation of the suspended gasoline and the gasoline layer within 15 years of the leak. According to Schwille, heavier oil products may remain in the soil for tens of years, whereas gasoline will not. Case histories of leaks show that gasoline has never remained in the soil for more than 15 years (Schwille, 1967, p. 38).

Locating Exploratory Drilling Sites

In November 1979, after a leveling survey determined precise altitudes of well measuring points, water levels were measured, and a generalized map of the configuration of the water table (similar to fig. 3) was drawn for field use. Based on the water-table map and an understanding of how gasoline spreads in the subsurface (Freeze and Cherry, 1979; Fried and others, 1979; Holzer, 1976; McKee and others, 1972; Dietz, 1971; Schwille, 1967; Van Dam, 1967; and Williams and Wilder, 1971), the extent of the spread of the gasoline was estimated to help in selecting sites for exploratory drilling. The estimate was based on assumptions concerning the volume of gasoline leakage, residual saturation of the alluvial material above the water table, and thickness of the gasoline layer above the water table. Gasoline leakage was assumed to be 5,000 gallons, the volume of the storage tank first reported by station operators. The residual saturation for the alluvium was assumed to be 0.05, based on geologists' and drillers' logs reporting poorly sorted gravelly silty sand. Finally, the thickness of the gasoline layer was assumed to be 0.117 inch (3 mm). Case histories of oil product leaks (Schwille, 1967, p. 36-37) indicate that where leaks have reached the final stages of spreading or have ceased spreading, layer thicknesses have never been less than 3-5 mm and are more likely to be several tens of millimeters. Using the thinnest layer thickness from case histories produced a maximizing of the spreading estimate used for locating exploratory drilling sites.

A basic estimate was made, using the stated values in the following equation, which assumes an even radius of spreading about the source of the gasoline:

$$r_s = \sqrt{\frac{V}{S_r L_t \pi}} = \sqrt{\frac{668}{(0.05)(0.01)\pi}} = 650 \text{ feet},$$

where

r_s = radius of spread, in feet,

V = volume of gasoline loss, in cubic feet, 668 ft^3 (5,000 gal),

S_r = residual saturation of the alluvium, 0.05, and

L_t = gasoline layer thickness, in feet, 0.01 foot (3 mm).

The radius of spread calculated was about 650 feet. It was realized, however, that much of the gasoline would be trapped by capillary and molecular forces in the unsaturated zone between the tank and the water table. Disregarding this fact, and therefore assuming that all gasoline reached the water table, would cause a further maximization of the value of r_s. It was also known that the gasoline that reached the water table would move primarily down the ground-water gradient. The r_s value was therefore doubled to 1,300 feet and considered a very rough estimate, leaving the option to relocate test-hole sites as exploratory drilling proceeded. This maximizing approach allowed for large error in making the estimate. For example, if 50,000 gallons of gasoline were actually lost and the layer thickness was actually 1.4 inches (36 mm), the spread should still be restricted within the 1,300-foot downgradient estimate. Layer thicknesses in a silty alluvium, according to a rough guide offered by Dietz (1971, p. 132), will be much thicker than the 1.4 inches used in the above example. Dietz' guide is as follows:

Sand	Average grain size, in millimeters (inches)	Thickness of layer, in centimeters (inches)
Extremely coarse to very coarse	2 to 0.5 (0.08 to 0.02)	1.8 to 9.0 (0.71 to 3.54)
Very coarse to moderately coarse	0.5 to 0.2 (0.02 to .008)	9.0 to 22.4 (3.54 to 8.82)
Moderately coarse to moderately fine	0.2 to 0.05 (.008 to 0.002)	22.4 to 28.1 (8.82 to 11.06)
Moderately fine to very fine	0.05 to 0.015 (0.002 to 0.0006)	28.1 to 45.0 (11.06 to 17.72)

Eight exploratory sites were selected in three directions from the gasoline source, including sites extending as far down ground-water gradient as well 15S/44E-36K3 (fig. 5), 900 feet to the east. Site locations were selected subject to change as exploratory drilling proceeded. Each site was surveyed for altitude and plotted on the field water-table contour map to obtain an estimated depth to the water table. These estimates of depth insured sampling of the soil immediately above the water table, and therefore detection of the gasoline layer if present.

Gasoline Losses From Service Station Records

In December 1979, service station operation records of purchases and sales of unleaded gasoline were obtained from Fred Harvey, Inc., concessionaire for Stovepipe Wells Hotel. Records indicate that leakage during the period October 7, 1978, to September 4, 1979, may have been as much as 19,000 gallons. Prior to October 1978 the hotel was privately owned and records were not made available to the authors; therefore, an accurate estimate of the total volume of gasoline leakage was not possible. The losses from October 7, 1978, to November 2, 1978, averaged about 74 gal/d; the losses from October 7, 1978, to September 4, 1979, averaged about 57 gal/d. Because the average losses for the first 27 days of record were more than the average losses for the entire period of record, the indication is that leakage began prior to October 7, 1978.

With the additional information concerning the volume of gasoline losses, it was realized that the original estimate of downgradient spreading of the gasoline layer was based on too small a volume. No modification of the exploratory sites staked in November was assumed necessary at that time, however, because the option to relocate exploratory wells could be exercised in the field as new data were obtained from drilling results.

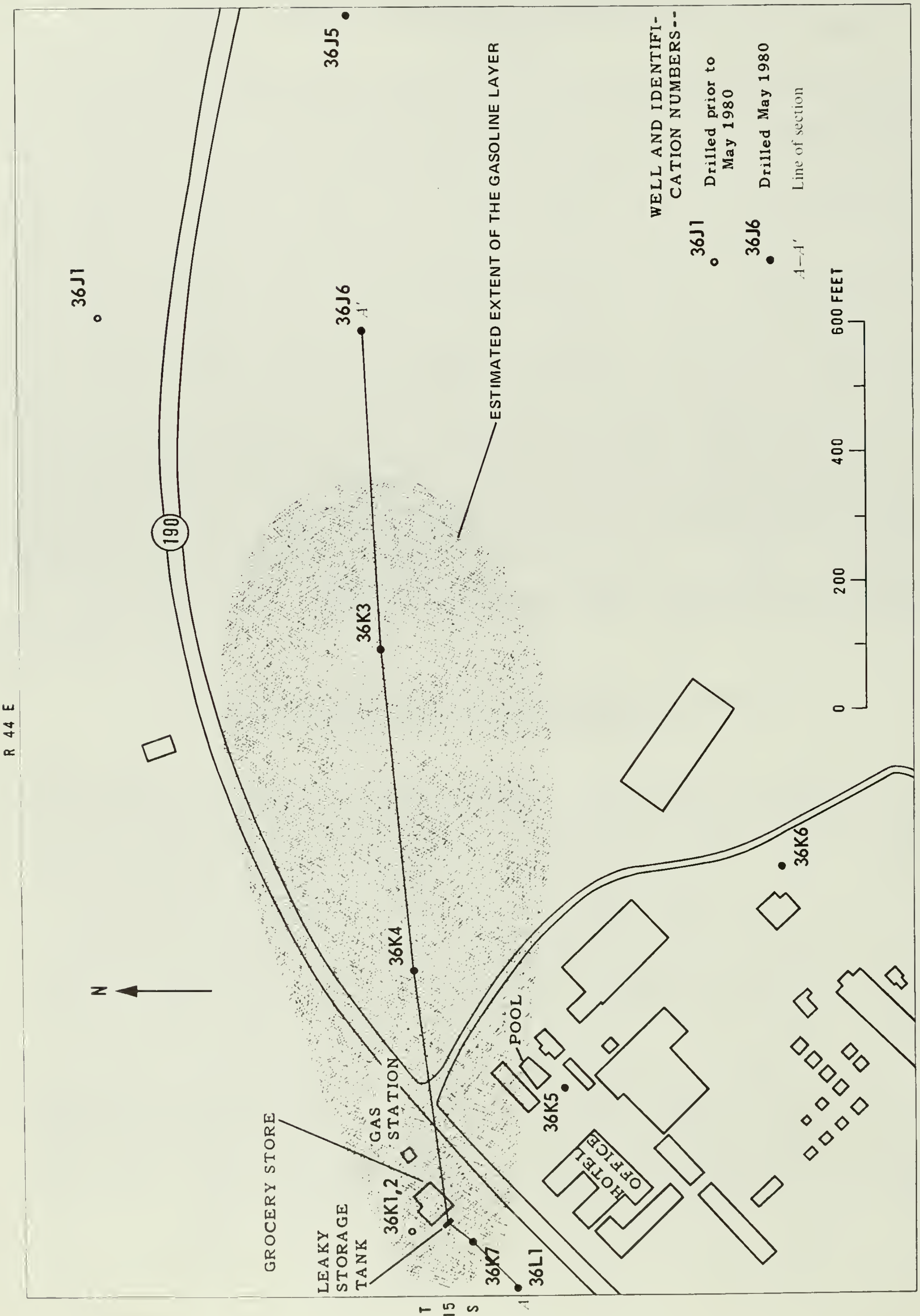


FIGURE 5.—Estimated horizontal extent of the gasoline layer, based on test drilling, May 1980.

Exploratory Drilling and Subsurface Soil Sampling

Exploratory drilling was done using an 8-inch hollow-stem auger and a split spoon soil sampler. Each hole was drilled to a depth of 2 to 3 feet above the estimated water table at seven sites and to 11 feet above at site 15S/44E-36K7 (fig. 5), the closest well to the gasoline source. A step-by-step drilling and soil-sampling operation was then begun in 1-foot increments to a maximum depth of 3.5 feet below the estimated water table. The procedure used was to collect 1 foot of soil from below the auger bit, drill to the bottom of the sample interval, and then collect another sample below the bit. This was repeated until the final sampling depth was reached. Soil samples were collected in metal sleeve inserts to the sampler. This technique minimized evaporation of the gasoline from the soil following collection and during shipment to the laboratory, and minimized contamination from previous samples. The test holes were then drilled to completion between 6 and 11 feet below the water table and converted to monitor wells. Two-inch PVC blank and slotted casings were installed to the well's final depth, and the perforated sections were enveloped in a clean sand pack and set to intersect above and below the water table. This setting of the perforations insured that any gasoline above the water table would flow into the well.

Table 2 shows the details of all soil samples collected, concentrations of gasoline in the sample, and descriptions of gasoline presence. A strong gasoline odor was detected in soil samples collected from the first test hole, 15S/44E-36K4 (fig. 5), located about 400 feet east and down ground-water gradient from the gasoline source. The second hole, site 36K3, 900 feet east of the source, had a layer of gasoline possibly more than 1 foot in thickness, according to two consecutive 1-foot thick gasoline-saturated samples. Gasoline was poured from the top of the sampler into glass bottles and allowed to settle for several hours with no observable separation of gasoline and water. The layer thickness prompted the selection of a new site for the third test hole, site 36J5, about 1,900 feet east of the source. No field-detectable gasoline was discovered at the site. Site 36J6, 1,400 feet east of the source, was drilled next, but no gasoline was detected there. The downgradient extent of the gasoline layer was then judged to be between 900 and 1,400 feet from the source. Test holes 36K6 and 36K5, 750 feet and 250 feet southeast of the source, respectively, were drilled next but showed no field detection of gasoline. The last two test holes, 36K7 and 36L1, were drilled 50 feet and 150 feet southwest of the source, respectively. Undiluted gasoline was found in 36K7, but no field-detectable gasoline was found in 36L1.

TABLE 2. - Gasoline concentrations in soil and water samples, Stovepipe Wells Hotel area

[Description of gasoline presence: CGI, concentrated gasoline, ignitable; GW, gasoline and water; SGO, strong gas odor; FGO, faint gas odor; and NGO, no gas odor]

State well No. (fig. 5)	Date	Water level (feet below lsd)	Sample depth (feet below lsd)	Gasoline concentration (μg/L)	Description of gasoline presence
			Soil samples		
15S/44E-36J5	5-13-80	36.26	33.0-35.5	------	NGO
			35.5-36.0	([1])	NGO
			36.0-38.0	------	NGO
15S/44E-36J6	5-14-80	37.90	36.0-37.4	------	NGO
			37.4-37.9	([1])	NGO
			38.0-38.5	------	NGO
15S/44E-36K3	5-13-80	39.42	37.0-38.0	------	NGO
			38.1-38.5	([1])	NGO
			38.5-39.0	([1])	NGO
			39.0-40.0	------	CGI
			40.0-41.0	------	CGI
			41.0-42.0	------	GW
			42.0-43.0	------	SGO
15S/44E-36K4	5-13-80	40.53	35.0-36.0	------	NGO
			37.0-37.5	7.29×10^5	NGO
			37.5-38.0	------	NGO
			39.0-39.5	------	NGO
			39.5-40.0	------	SGO
			40.0-40.5	------	SGO
			41.1-41.6	------	NGO
			42.3-42.8	------	NGO
15S/44E-36K5	5-14-80	49.06	46.0-49.3	------	NGO
			49.3-49.8	1.12×10^4	NGO
			50.0-50.5	------	NGO
			50.5-51.0	1.57×10^4	NGO
			51.0-52.0	------	NGO
15S/44E-36K6	5-14-80	63.62	61.0-61.5	------	NGO
			61.5-62.0	([1])	NGO
			62.0-62.5	------	NGO
			62.5-63.0	([1])	NGO
			63.0-65.0	------	NGO

See footnote at end of table

TABLE 2. - Gasoline concentrations in soil and water samples, Stovepipe Wells Hotel area--continued

State well No. (fig. 5)	Date	Water level (feet below lsd)	Sample depth (feet below lsd)	Gasoline concentration (μg/L)	Description of gasoline presence
			Soil samples		
15S/44E-36K7	5-18-80	42.53	30.0-36.5	------	NGO
			36.5-37.0	(1)	NGO
			37.0-37.5	------	NGO
			37.5-38.0	(1)	NGO
			38.0-38.4	------	NGO
			38.4-38.9	(1)	NGO
			39.0-39.4	------	NGO
			39.4-39.9	(1)	NGO
			40.0-40.3	------	FGO
			40.3-40.8	(1)	FGO
			41.0-41.4	3.65×10^5	FGO
			41.4-41.9	------	FGO
			42.0-42.5	------	SGO
			42.5-43.0	2.71×10^6	SGO
			43.0-44.0	------	CGI
			44.0-45.0	------	FGO
15S/44E-36L1	5-15-80	45.07	42.0-44.5	------	NGO
			44.5-45.0	1.7×10^4	NGO
			45.0-45.5	(1)	NGO
			45.5-47.0	------	NGO
			Water sample		
15S/44E-36K1	5-30-79	37.56	37.56-38.56	undiluted gasoline[2]	

[1]Soil sample analyzed for hydrocarbons. No gasoline detected. Limit of detection is about 3×10^3 μg/L.
[2]Undiluted gasoline equals 6.72×10^8 μg/L.

Selected soil samples, primarily from zones where no field-detectable gasoline was found, were sent to the U.S. Geological Survey's Central Laboratory for analysis for hydrocarbon concentration. The samples, having been collected in metal sleeve inserts to the split-spoon sampler, were sealed with aluminum foil and tape, placed in sealable plastic bags, and refrigerated for shipment to the laboratory. A vial of gasoline was collected from test hole 15S/44E-36K3 for use as a laboratory standard. Hydrocarbons were extracted into acetone-hexane and then analyzed by gas chromatograph/mass spectrometry. Table 2 includes analyzed concentrations of gasoline found in the soil samples. Laboratory analyses detected gasoline in very low concentrations at two test sites where no field detection was made. Test holes 36K5 contained 1.12×10^4 µg/L and 36L1 contained 1.7×10^4 µg/L in samples collected at the water table. The concentrations are less than 0.002 percent hydrocarbons in water, and probably represent the diffusion of water-soluble components of gasoline into the aquifer, not the gasoline layer. The estimated horizontal spread of the gasoline layer was mapped (fig. 5) on the basis of field detection and sample analyses. Figure 6 shows a diagrammatic cross section of trace A-A' shown in figure 5. The purpose for the cross section is to graphically demonstrate how the subsurface zones are affected by the leaky gasoline storage tank. The size and boundaries of affected areas are not representative of the actual contamination at Stovepipe Wells Hotel but were meant for schematic purposes only.

Hydrologic Effects of the Gasoline Leak

No major impact on the area's water supply is expected from the gasoline leak unless a significant change occurs in the direction of ground-water movement. The direction of ground-water movement is the primary factor controlling the direction of movement of both the gasoline layer and the gasoline solutes in the aquifer water. Ground-water movement in the area is eastward (fig. 2); and supply wells 16S/44E-1C1 (reverse-osmosis supply well) and 15S/44E-36Q2 are about 0.4 mile south 5° west and south 23° east, respectively, of the gasoline leak site, not within the expected path of movement of the gasoline. The low hydrocarbon concentrations found in soil samples from test well 15S/44E-36K5 (table 2) indicate that the soluble gasoline components have migrated farther toward the supply wells than the gasoline layer has. Future monitoring of wells 15S/44E-36K5 and 15S/44E-36K6 will determine if either the gasoline layer or the solutes migrate farther toward those wells. In the unlikely event that low concentrations of gasoline solutes should reach the supply wells, their effects, such as disagreeable taste and odor, could be eliminated by a combination of aeration and activated charcoal filtration (Williams and Wilder, 1971, p. 51, 56).

Effects on phreatophytic plants would be of major concern if they were present in the area of the gasoline layer. The roots of these plants, in obtaining a water supply from below the water table, would penetrate through the gasoline layer. Fortunately, the nearest phreatophytes are located upgradient, about 0.3 mile northwest of the leak. Downgradient the nearest phreatophytes are located about 2 miles east of the leading edge of the gasoline layer as estimated in May 1980 (off fig. 5 to east). Future movement of the gasoline layer is not expected to extend that far. Monitoring of wells 15S/44E-36J5 and 36J6 would reveal any continued migration of the gasoline layer to the east. If gasoline extends past these wells, additional wells installed farther east would be required to continue the monitoring.

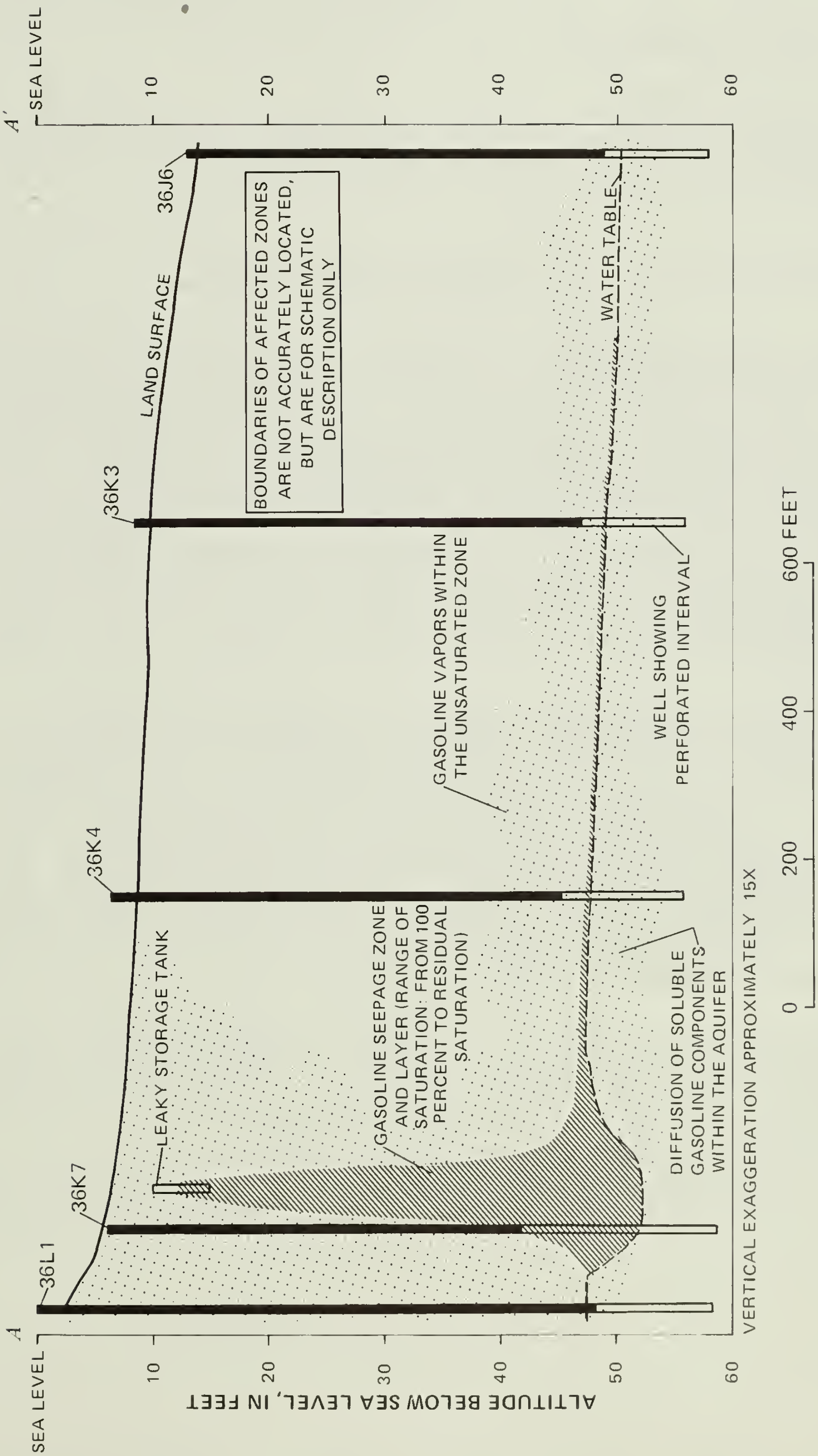


FIGURE 6.--Diagrammatic cross section of trace A—A′ (fig.5) through the gasoline contaminated area.

Xerophytic plants throughout the study area obtain water from soil moisture above the water table and will therefore not come in contact with the gasoline layer. What effect the gasoline vapors will have on these plants as the vapors continue to diffuse through the unsaturated zone is not known. No effects have been observed so far.

Complete biodegradation and evaporation of the gasoline will probably occur within 15 years of the leak. This would limit the duration of possible effects on both the water supply and the vegetation.

SUMMARY AND CONCLUSIONS

Following the detection of gasoline in an unused well at Stovepipe Wells Hotel, Calif., the horizontal extent of a gasoline layer overlying the water table was delineated by exploratory drilling and split-spoon soil sampling. The gasoline layer was found to extend between 900 and 1,400 feet downgradient (east) and between 50 and 150 feet upgradient from the leak source. Traces of hydrocarbons resulting from the diffusion of the slightly soluble gasoline components were also found in the aquifer 150 feet upgradient and 250 feet normal to the direction of ground-water movement (south) from the leak. Future monitoring of local wells, especially in the direction of the supply wells (south), will be necessary to determine the extent of continued movement of both the gasoline layer and the slightly soluble gasoline components within the aquifer.

Because of the present direction of ground-water movement in the area, no effects on the local water supply or phreatophytes are expected. The supply wells are about 0.4 mile south of the leak site, nearly perpendicular to the direction of ground-water movement and the primary direction of gasoline movement in the area. Should traces of gasoline solutes reach the supply wells, aeration and activated charcoal filtration of the water could alleviate adverse effects on taste and odor. The nearest phreatophytes are upgradient, 0.3 mile northwest of the leak site. Phreatophytes downgradient are about 2 miles east of the leading edge of the gasoline layer, as estimated in May 1980, farther from the leak site than the layer is ever expected to extend.

The potential effects on xerophytes of the diffusion of gasoline vapors within the unsaturated zone is not known. Xerophytes grow throughout the study area, but so far no effects from the gasoline leak have been noticed.

Complete evaporation and biodegradation of the gasoline above the water table will probably occur within 15 years of the leak. This would limit the duration of its possible adverse effects on both the water supply and the vegetation.

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